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TECHNICAL REPORT ARLCD-TR-83056

MINIMUM NONPROPAGATION DISTANCE FOR THE CLOUD DETONATOR OF THE XM130 SLUFAE ROCKET

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FEBRUARY 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of an Army-wide expansion and modernization program, safe separation distance criteria for the cloud detonator of the XM130 SLUFAE rocket and its assembly table were determined after study and testing. Two test series were involved: (1) a standard nonpropagation series for present table spacing of the detonators and the use on future conveyor systems, and (2) a series of structural integrity tests to determine the adequacy of the intrastation partitions. These tests established and statistically confirmed that a (cont)

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18. SUPPLEMENTARY NOTES (cont)

the production of Army materiel. Test coordination and basic data reduction were accomplished by the ARDC Resident Operations Office, National Space Technology Laboratories, NSTL Station, Mississippi. Both exploratory and confirmatory tests were conducted by the Hazards Range Support Unit of Computer Science Corporation at NSTL.

20. ABSTRACT (cont)

122 cm (48 in.) free-air spacing between detonators would yield a 7.11% probability of propagation at the 95% confidence level; also, that the 1.27 cm (0.5 in.) thick steel wall between the work stations of the assembly table is sufficient to protect adjacent operators from accidental detonation fragments.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to R. Brack of the ARDC Resident Operations Office, National Space Technology Laboratories, Mississippi, for the preparation of the detailed test plans and the coordination of the actual test program; and to R. Amend, L. Mars, S. Fuentes, H. Stover and G. Richardson of the Hazards Range Support Unit, Computer Science Corporation, NSTL Station, Mississippi, for conducting both series of exploratory and confirmatory tests and collating the resulting data.

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INTRODUCTION

Background

An Army-wide modernization program is in the process of upgrading existing, and developing new, explosive manufacturing and load, assemble, and pack (LAP) facilities. This on-going, programmed effort will enable the U.S. Army to achieve ever-increasing production cost effectiveness with improved functional safety of the assembly line man-item relationship, as well as to provide manufacturing capabilities for future weaponry systems within the existing buildings and facilities at currently active Army Ammunition Plants (AAPs). As an integral part of this program, the U.S. Army Armament Research and Development Center is engaged in the continuous development of functionally responsive safety criteria as an activity entitled "Safety Engineering in Support of Ammunition Plants," which includes the establishment of safe separation (nonpropagation) distance studies of munition end-items, explosive subcomponents, and in-process bulk explosive materials. The criteria, developed for this program, will be used as part of the basis for the design of all explosive installations due for modernization, and will be available for reference purposes to privately owned and operated (POPO) plants engaged in ordnance-related manufacturing operations.

The protective technology included in this report provides safety criteria data to specifically support facility modernization provisions in the overall LAP concept for the assembly of cloud detonator subcomponents of the XM130 surface launched unit fuel air explosive (SLUFAE) rocket system in support of the modernization project at Hawthorne AAP.

Since the presently planned LAP operations for the XM130 SLUFAE rocket system, and thus its subcomponents, are for a low volume, hand assembly sequence, the safety testing for the cloud detonator was based on the use of a standard three-bay loading table (fig. 1). Two series of tests were configured and mutually agreed on: (1) a standard safe separation (nonpropagation) distance test sequence to determine how far apart the cloud detonators should be kept, and (2) a test sequence to insure the structural integrity of the walls between the assembly table loading bays.

Objective

The primary objective of this program is to establish and statistically confirm, through experimental evaluation, the safe nonpropagation separation distance between cloud detonators for the XM130 SLUFAE rocket system. As a secondary objective, tests were conducted to insure that an accidental detonation of a cloud detonator at one work station on the assembly table would not breach the walls between work stations and send fragments into adjacent stations.

The overall program objective is to supplement and/or modify the existing safety regulations and criteria pertaining to the safe spacing of ammunition and other energetic materials to assist explosive loading plants in their LAP facility layouts.

Criteria

This test program was implemented to determine the safe spacing between two cloud detonators and to insure the structural integrity of its assembly table as presently designed. This safe spacing is necessary to insure that the effects of a major unscheduled detonation of one cloud detonator within an assembly area will not be propagated to other cloud detonators and result in a disaster. The insurance of the structural integrity of the assembly table walls will protect adjacent work areas if an accidental detonation occurs. Therefore, the only acceptable criterion in the establishment of the safe nonpropagation distance is to eliminate the donor detonation to the acceptor units. Also, the only acceptable criterion for establishment of the structural integrity of the assembly table is the complete confinement of donor blast fragments to the originating work area.*

TEST CONFIGURATION

Testing of the cloud detonators for the XM130 SLUFAE rocket system to establish and statistically confirm the minimum nonprogagation distance between donor and acceptor units under simulated manufacturing line conditions, and to determine the structural integrity of the assembly table walls was conducted by the ARDC Resident Operations Office at the hazard test range of the National Space Technology Laboratory in Mississippi.

Test Specimen

For this test program, two types of specimens, real and simulated, were used. The real test specimens were fully assembled cloud detonators (fig. 2); however, due to the scarcity of subcomponents to build up the necessary simulated test specimens, they were only used as acceptor units in the confirmatory phase of the safe separation distance testing and in the assembly table structural integrity tests. All safe separation distance exploratory tests and the donor units of the confirmatory tests used the simulated cloud detonators (fig. 3).

The fully assembled cloud detonator (fig. 2) functions in the following manner: pressurization of the rocket motor support chamber to which the back (or left) end of the cloud detonator is threaded, causes the firing pin's shear wire to shear. The firing pin then impacts the delay detonator and, at the same time, pushes the actuator rod forward (to the right), compressing a spring. The spring pushes on the plunger which, in turn, pushes on the slider assembly. The slider assembly is then restrained from moving into explosive alignment by the safety rod and restrained in the out-of-line position by contacting the inside diameter of the launch tube, thus causing a secondary boreriding safety. The original

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* All safe separation distances specified in this report are measured from centerline to centerline between the cloud detonators

chamber pressurization also causes an obturator and all other internal cloud detonator components to accelerate forward. When the obturator has moved forward far enough to contact the shoulder on the inside diameter of the launch tube, it ceases its forward motion. However, the delay holder and other internal components continue to move and exit the launch tube. The safety rod, which is attached to the obturator, stays within the launch tube and allows the slider assembly to align with the delay detonator. The slider assembly is now locked in permanent alignment by the spring-loaded plunger assembly. Meanwhile, the impacted delay detonator has ignited and after the appropriate delay time, fires through the aligned slider assembly and initiates the booster pellets. A list of the hazardous elements found within the cloud detonator assembly is given in table 1.

The simulated cloud detonators (fig. 3) contained the same type, quantity, and weight (2 pellets/66.5 g of PBXN-5) of explosive as the booster charge in the real assembly. Also, the launch tube and delay holder materials were the same grades of steel and nylon, respectively. Therefore, the simulated cloud detonators were considered to have the same explosive potential and blast/fragmentation pattern as the real units. Since the other hazardous materials in the fully assembled cloud detonator (delay detonator, delay train, and lead cup assembly) are part of an out-of-line fuze train and only represent a minor amount of explosive material (approximately 2% by weight), they were left out of the simulated cloud detonators.

Test Arrangements

Safe Separation Distance Tests

Each test layout consists of one donor and two acceptor cloud detonators arrayed in a straight line and raised off the ground to simulate the average standoff distance of the assembly table (or conveyor system) above the building floor (fig. 4). The center specimen served as the donor, or initiated cloud detonator, while the cloud detonators on either side served as the acceptor specimens, thus producing two acceptor sets of test data results for each test donor detonated. During the exploratory test phase, and within the single test firings, the test separation distance between the donor and acceptor cloud detonators was varied from test to test. However, during the confirmation test phase, the donor-to-acceptor separation distance was always held constant.

The exploratory phase of the nonpropagation distance tests consisted of a test array of three unbarricaded cloud detonators arranged in a linear position and mounted on a 2.54 cm by 30.48 c (1.0 in. by 12.0 in.) pine board to simulate the table, or conveyor, in the assembly facility. The test cloud detonators and simulated table top were supported by low density concrete blocks approximately 45.7 cm (18 in.) above the existing terrain. During this exploratory phase, which consisted of seven test detonations, the separation distances measured centerline to centerline between cloud detonators, and ranged from 7.6 cm to 122 c (3.0 in. to 48.0 in.). This spacing was held constant for all the confirmatory tests.

Structural Integrity Tests

The initially planned test layout (fig. 5) consisted of two 1.27 cm (0.5 in.) AISI 1010-1020HRS steel plates, one vertical and one horizontal, to simulate the assembly table and its loading station partitions. Each test consisted of one cloud detonator placed on the horizontal plate and against the vertical plate with the axis of the cloud detonator parallel to the vertical plate. This configuration would simulate the worst case accidental detonation and determine the structural integrity of the partitions of the assembly table. If, with the cloud detonator against the vertical plate, the detonation penetrated and threw fragments into the next work area, it was planned to determine the necessary standoff spacing to prevent partition breachment by donor fragments. A series of six detonations were initiated with this test array to insure the structural integrity of the assembly table partition.

Based on witness plate results from the safe separation distance test phase, namely, the cloud detonator in the nose down position acting like a shaped charge and completely piercing a 1.27 cm (0.5 in.) steel witness plate, a second series of structural integrity tests were conducted with the axis of the cloud detonator perpendicular to the partition and its forward end touching the partition.

Method of Initiation

In all cases where the donor cloud detonators were simulated (fig. 3), they were primed and initiated with an engineer's special J2 blasting cap without using a boosting charge. The blasting cap, in all cases, was inserted in the firing well provided in the simulated cloud detonators. When fully assembled cloud detonators were used as donors, as in the assembly table structural integrity tests, the nose end was primed with the same engineer's blasting cap but containing a booster of 15 g (0.45 oz.) of C4 explosive. These methods of initiation insured that the donor specimen always detonated to a high order explosion, which was further confirmed by the examination of the steel witness plates after detonation.

TEST RESULTS

As previously stated, this test program is based on the low volume hand assembly of cloud detonators of the XM130 SLUFAE rocket system on a specific assembly table. Therefore, the test program was divided into two distinct but interrelated phases: (1) safe separation distance tests to establish and statistically confirm the nonpropagation distance between cloud detonators, and (2) structural integrity tests to determine the adequacy of the assembly table barricades to contain an accidental detonation within the event's work station.

Safe Separation Distance Tests

Seven exploratory tests were conducted using various separation distances (measured between cloud detonator centerlines), ranging from a minimum of 7.6 cm to 122.0 cm (3.0 in. to 48.0 in.) as shown in table 2, test numbers 1 through 7, inclusive. While no high order detonations were authenticated during the post-test examination of the acceptors, there was a sufficient amount of damage (fragment penetrations and composition burning) at distances out to and including 92.0 cm (36 in.), to establish 122.0 cm (48 in.) as the distance for the confirmatory test phase.

The pretest views of this test series are: (1) an exploratory test with different spacings for the left and right acceptors (fig. 6) and (2) a confirmatory test with the acceptors at the 122.0 cm (48 in.) centerline spacing (fig. 7). Various posttest views of the series are shown in figures 8 through 11. The damages done to the witness plates by the donor detonation, the fragment penetrations of acceptors by the donor detonation, the results of a low order detonation of an acceptor, and a confirmation test acceptor series with minimal noticeable damages are shown in figures 8 through 11, respectively.

The confirmatory test phase was initiated using a distance of 122.0 cm (48.0 in.) with 25 tests being conducted as shown in table 2, test numbers 8 through 32, inclusive. In all cases, fully assembled cloud detonators were used in the acceptor positions. As noted from the test results, relatively minor acceptor damage was incurred, and there was only one case of a donor being initiated to a deflagration.

Structural Integrity Tests

Six tests were conducted with the cloud detonator axially aligned with the wall of the simulated assembly table (fig. 12). The results in table 3, test numbers 1 through 6, with zero spacing (cloud detonator against the wall), show that the wall only bulged and split with no fragments coming through. The test results, showing the simulated front and back view of the assembly table wall, are shown in figures 13 and 14, respectively.

Due to the damage incurred to the witness plates during the safe separation tests, the cloud detonators may have greater penetrating power if the forward end is placed against the simulated wall; therefore, a second series of structural integrity tests were conducted using this orientation. After only two tests, numbers 7 and 8 of table 3, the series was discontinued because there was considerably less damage with this orientation than with the axial orientation. The pretest and posttest views of this series are shown in figures 15 and 16.

Analysis of Results

Variations in manufacturing tolerances, materials, wear, etc., required that statistical methodology be employed when interpreting the confirmatory phase safe

separation test data. The actual probability of the continuous propagation of an unexpected explosive incident at a LAP facility ammunition production line is a function of the number of propagation occurrences in a particular confirmatory test phase as compared to the total number of test detonations conducted within that phase. The statistical theory for explosion propagation is given in the appendix.

In the confirmatory phase of the safe separation (nonpropagation) distance test for the cloud detonator of the XM130 SLUFAE rocket system, 50 valid data points were recorded from the 25 test initiations, without a single propagation of the donor detonation, using a 122.0 cm (48.0 in.) spacing between cloud detonators. An upper limit of 7.11% probability of propagation of an explosive incident at the 95% confidence level has been calculated using the following parameters.

Similarly, in a large number of tests, 95 out of every 100 times an unexpected explosive incident occurs, the probability of its propagating to a catastrophic incident will be less than, or equal to, 7.11%. This value is an indication of the quality of the test results and the reliance that can be placed on the conclusions drawn from the data.

Structural integrity tests were conducted on simulated walls for the assembly table of the cloud detonator to insure that the walls between work stations will remain intact during and immediately after the accidental detonation of the cloud detonator.

CONCLUSIONS

It may be concluded from the results of the cloud detonator nonpropagation test program for the XM130 surface launched unit fuel air explosive rocket system that the 122.0 cm (48.0 in.) safe separation spacing between cloud detonators sufficiently deters the potential propagation of an unexpected explosive incident. With this arrangement, the probability of an explosive incident is 7.11% at the 95% confidence level.

It may also be concluded that the tests conducted on a wall simulating the ones between work stations on the cloud detonator's assembly table insured structural integrity of the walls.

Table 1. Hazardous materials used in cloud detonators

Subcomponent	Material	Quantity (g)
Delay detonator, M426 primer	Potassium chlorate (53%)	0.022
	Lead sulfocyanate (26%)	
	Glass (17%)	
	TNT (5%)	
Delay train	Delay mix	1.250
	Lead azide	0.060
	RDX	0.024
Lead cup assembly	PBXN-5	0.040
Booster	PBXN-5	66.5

Table 2. Safe separation distance tests for cloud detonator of XM130 SLUFAE rocket

Test[a,b]		Centerline distance cm	(in.)	Remarks[c]
1	L	30	(12)	Two penetrations, many hits
	R	15	(6)	Destroyed, possible HOD or LOD
2	L	45	(18)	Not found
	R	7.6	(3)	LOD
3	L	61	(24)	One penetration, many hits
	R	45	(18)	LOD
4	L	92	(36)	NDP, no damage
	R	77	(30)	One hit
5	L	77	(30)	Two penetrations, many hits, 100% burn
	R	77	(30)	Two penetrations, many hits, 75% burn
6	L	122	(48)	Three hits
	R	92	(36)	Two penetrations, three hits
7	L	122	(48)	Three hits
	R	122	(48)	One hit
8	L	122	(48)	NDP, three hits
	R	122	(48)	NDP, three hits
9	L	122	(48)	NDP, one hit
	R	122	(48)	NDP, two hits
10	L	122	(48)	NDP, two hits and one penetration
	R	122	(48)	NDP, one hit
11	L	122	(48)	NDP, two hits
	R	122	(48)	NDP, three hits

[a] Acceptors were simulated cloud detonators in tests 1 through 7 and fully assembled cloud detonators in tests 8 through 32.

[b] L,R: Left or right acceptor placed at different spacings.

[c] Definitions: HOD - high order detonation; LOD - low order detonation; X% burn - amount of PBXN-5 burned; penetrations - went through outer casing into explosive; hits - marked or lodged within outer casing, did not make contact with explosive; and NDP - no detonation propagation.

Table 2. (cont)

Test[a,b]		Centerline distance cm	(in.)	Remarks[c]
12	L	122	(48)	NDP, four hits
	R	122	(48)	NDP, three hits
13	L	122	(48)	NDP, one hit
	R	122	(48)	NDP, two hits
14	L	122	(48)	NDP, one hit
	R	122	(48)	NDP, one hit
15	L	122	(48)	NDP, two hits
	R	122	(48)	NDP, one hit
16	L	122	(48)	NDP, two hits and 1 penetration
	R	122	(48)	NDP, three hits
17	L	122	(48)	NDP, three hits
	R	122	(48)	NDP, three hits
18	L	122	(48)	NDP, three hits
	R	122	(48)	NDP, two hits
19	L	122	(48)	NDP, two hits
	R	122	(48)	NDP, one hit
20	L	122	(48)	NDP, one hit, one penetration and 30% burn
	R	122	(48)	NDP, three hits
21	L	122	(48)	NDP, two hits
	R	122	(48)	NDP, two hits
22	L	122	(48)	NDP, one hit and one penetration
	R	122	(48)	NDP, two hits

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[a] Acceptors were simulated cloud detonators in tests 1 through 7 and fully assembled cloud detonators in tests 8 through 32.

[b] L,R: Left or right acceptor placed at different spacings.

[c] Definitions: HOD - high order detonation; LOD - low order detonation; X% burn - amount of PBXN-5 burned; penetrations - went through outer casing into explosive; hits - marked or lodged within outer casing, did not make contact with explosive; and NDP - no detonation propagation.

Table 2. (cont)

Test[a,b]	Centerline distance cm	(in.)	Remarks[c]
23 L	122	(48)	NDP, one hit and two penetrations
R	122	(48)	NDP, two hits
24 L	122	(48)	NDP, one hit
R	122	(48)	NDP, two hits
25 L	122	(48)	NDP, three hits
R	122	(48)	NDP, one hit and one penetration
26 L	122	(48)	NDP, one hit
R	122	(48)	NDP, one hit
27 L	122	(48)	NDP, one hit
R	122	(48)	NDP, three hits
28 L	122	(48)	NDP, no damage
R	122	(48)	NDP, two hits
29 L	122	(48)	NDP, one hit
R	122	(48)	NDP, one hit
30 L	122	(48)	NDP, four hits
R	122	(48)	NDP, one hit
31 L	122	(48)	NDP, four hits
R	122	(48)	NDP, two hits
32 L	122	(48)	NDP, two hits
R	122	(48)	NDP, one hit

[a] Acceptors were simulated cloud detonators in tests 1 through 7 and fully assembled cloud detonators in tests 8 through 32.

[b] L,R: Left or right acceptor placed at different spacings.

[c] Definitions: HOD - high order detonation; LOD - low order detonation; X% burn - amount of PBXN-5 burned; penetrations - went through outer casing into explosive; hits - marked or lodged within outer casing, did not make contact with explosive; and NDP - no detonation propagation.

Table 3. Structural integrity tests for the assembly table of cloud detonator

Test*	Results
1	Deep bulge and split, no fragments through plate
2	Deep bulge and split, no fragments through plate
3	Deep bulge and split, no fragments through plate
4	Deep bulge and split with small hole, no fragments through plate
5	Deep bulge and split, no fragments through plate
6	Deep bulge and split, no fragments through plate
7	Shallow dent in plate, no fragment penetration of plate
8	Shallow dent in plate, no fragment penetration of plate

* Tests 1 through 8 - zero spacing (cloud detonator against wall); tests 1 through 6 - cloud detonator axially aligned (parallel) to wall; tests 7, 8 - forward end against wall (90°).

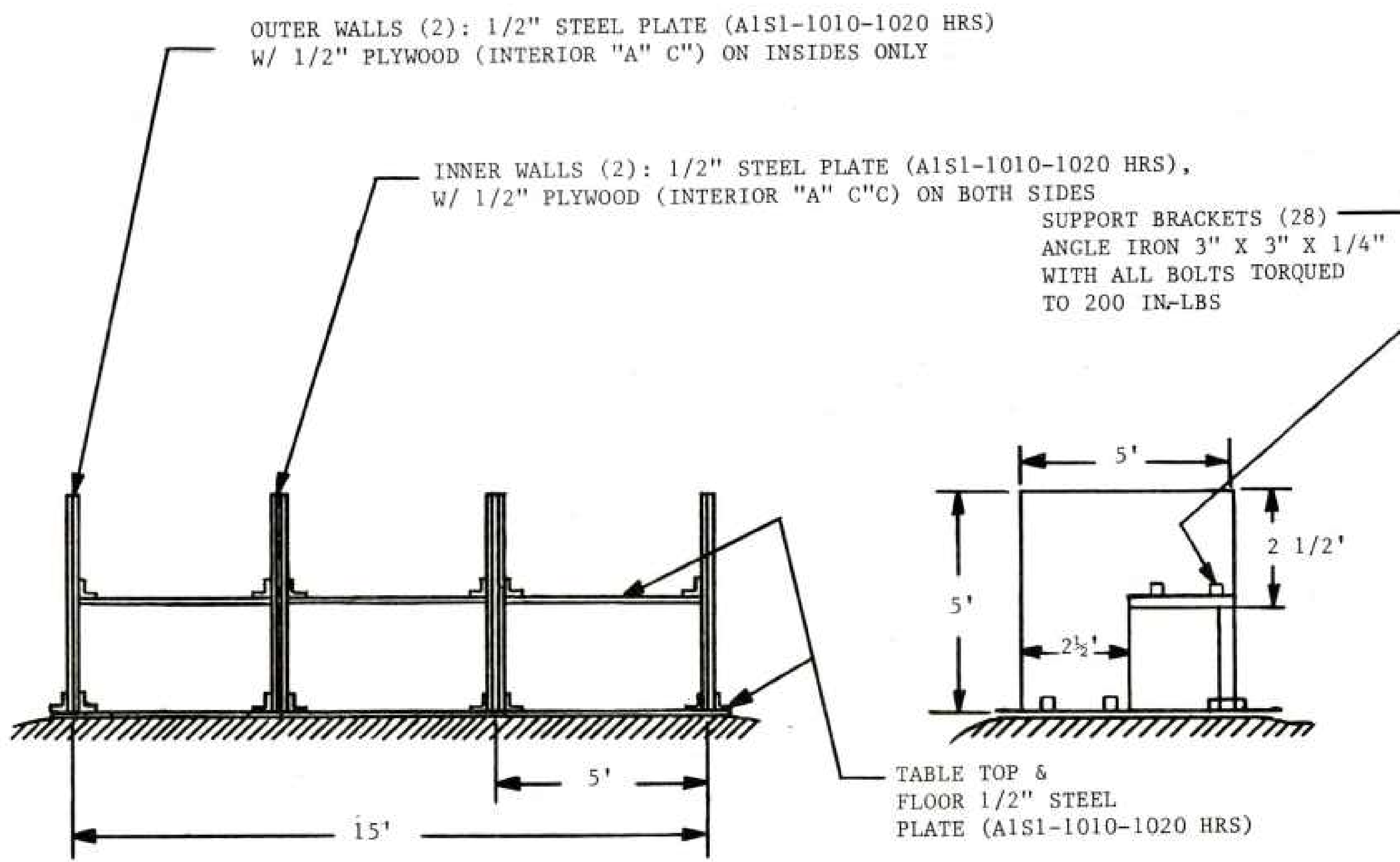


Figure 1. Cloud detonator assembly table for the XM130 SLUFAE rocket system

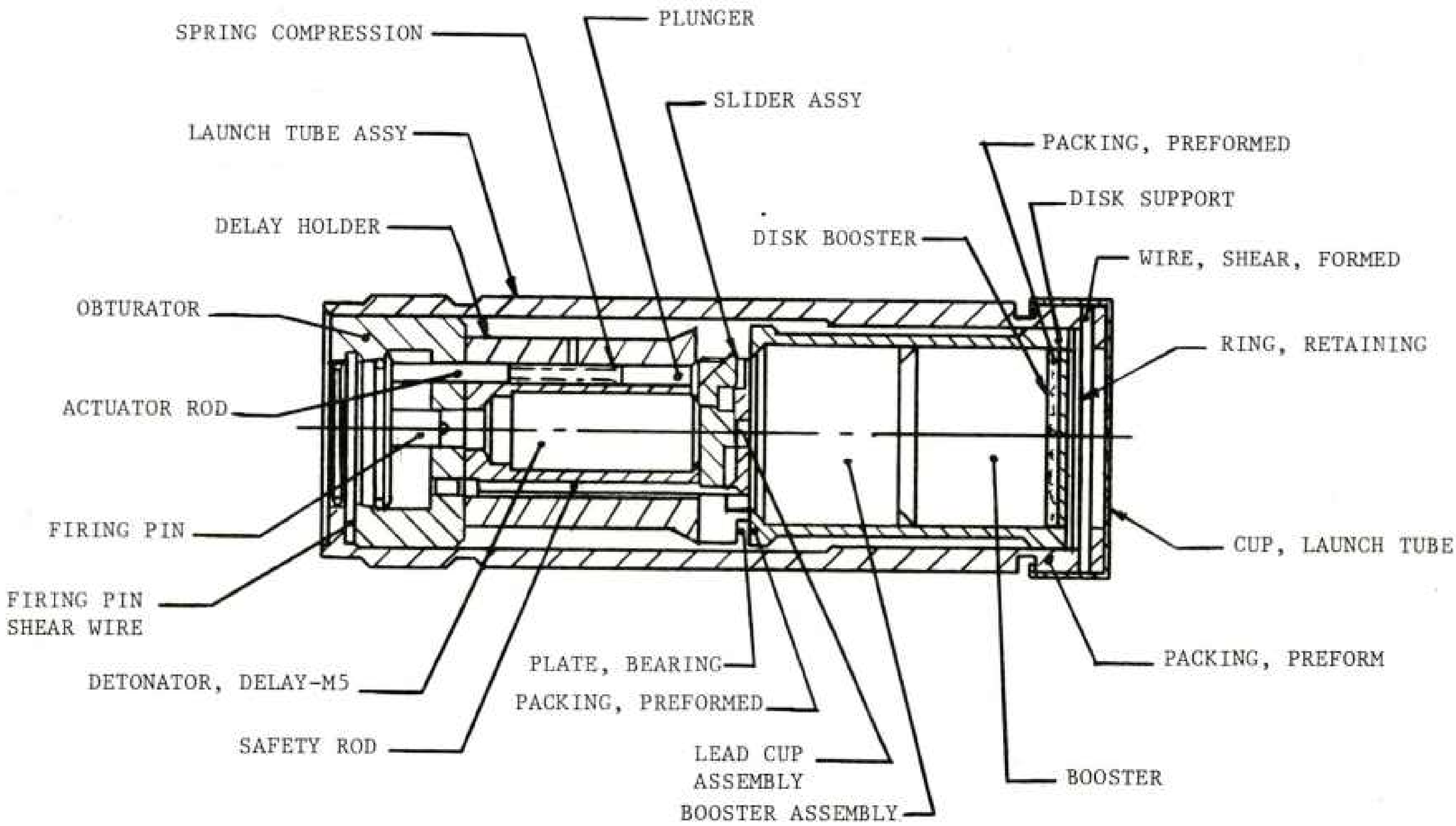
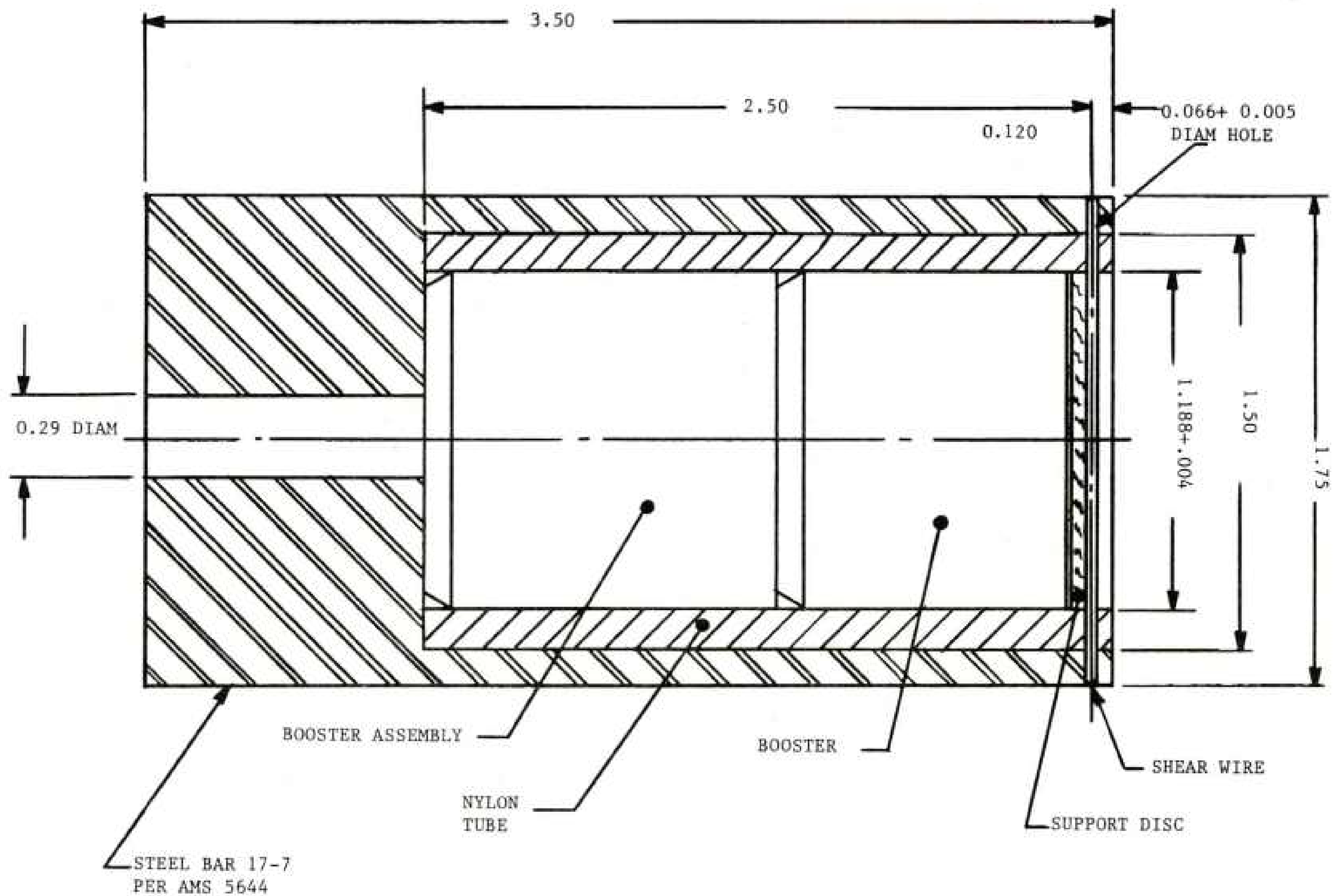


Figure 2. Cloud detonator



Note: All dimensions are in inches.

Figure 3. Simulated cloud detonator

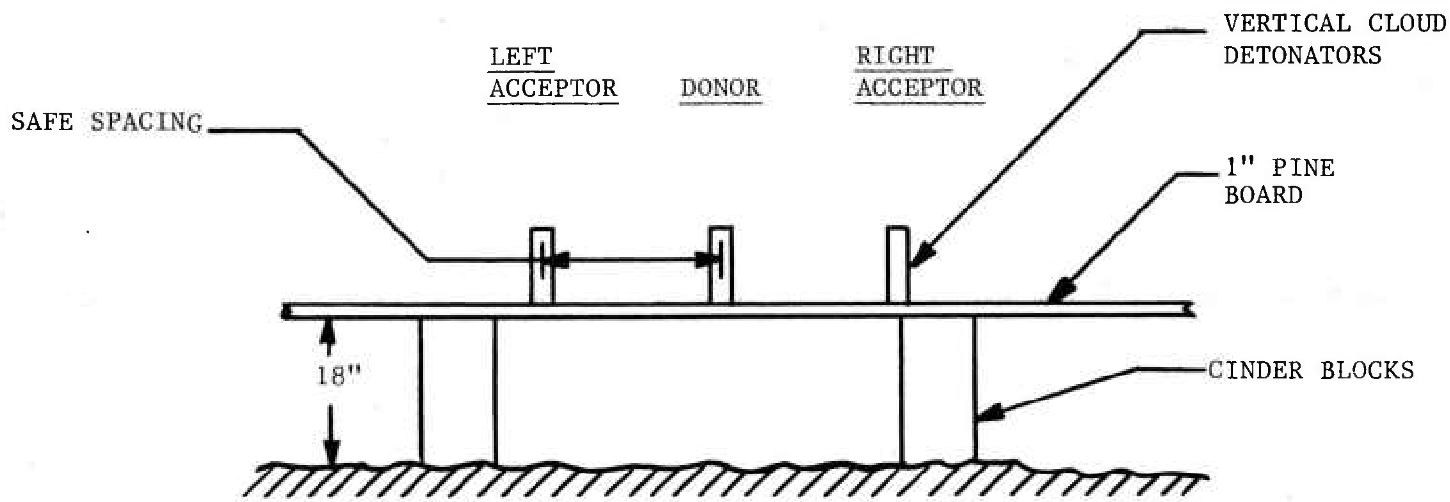


Figure 4. Cloud detonator safe separation distance test array

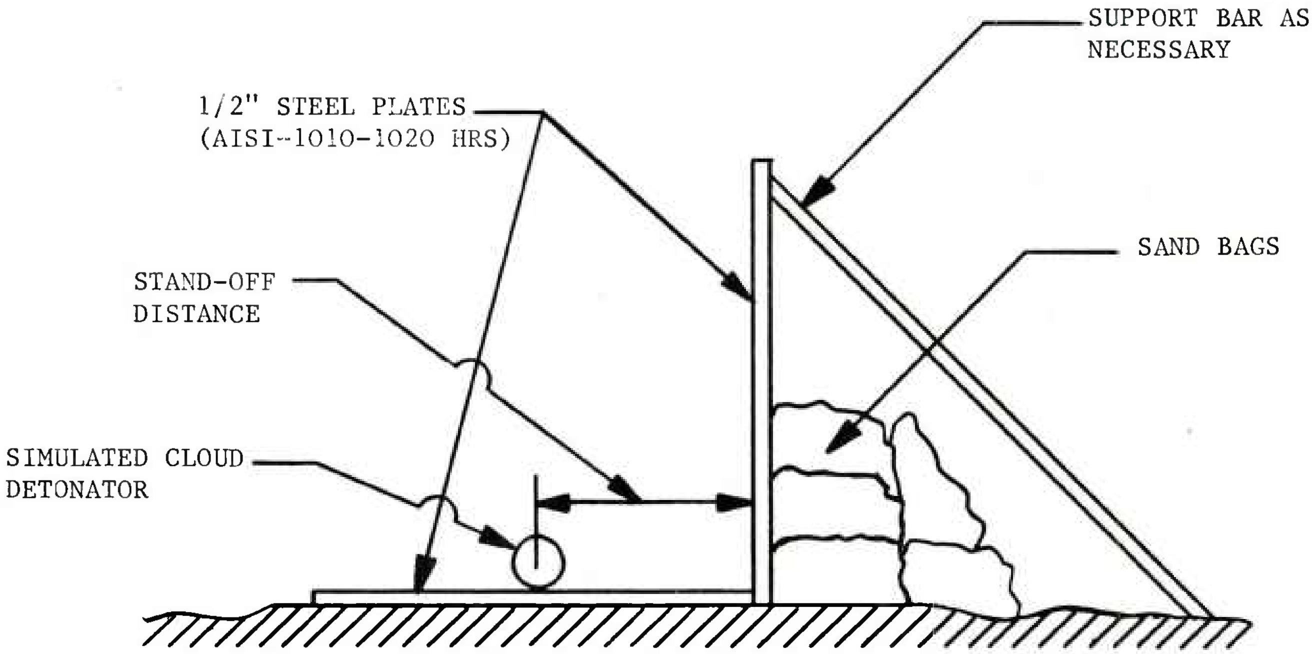


Figure 5. Cloud detonator penetration test array

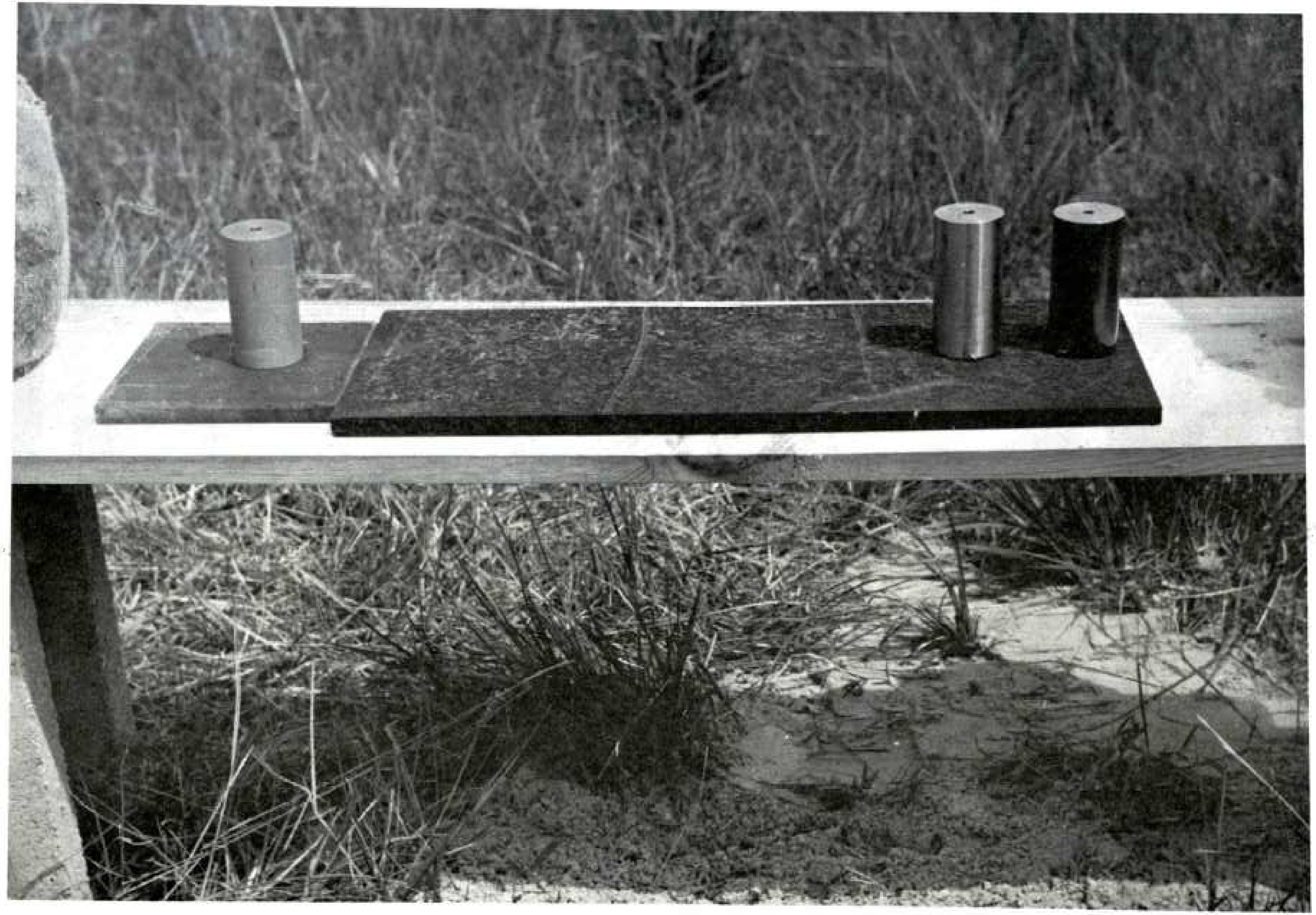


Figure 6. Exploratory nonpropagation test array

Figure 7. Confirmatory nonpropagation test array

Figure 8. Posttest witness plates

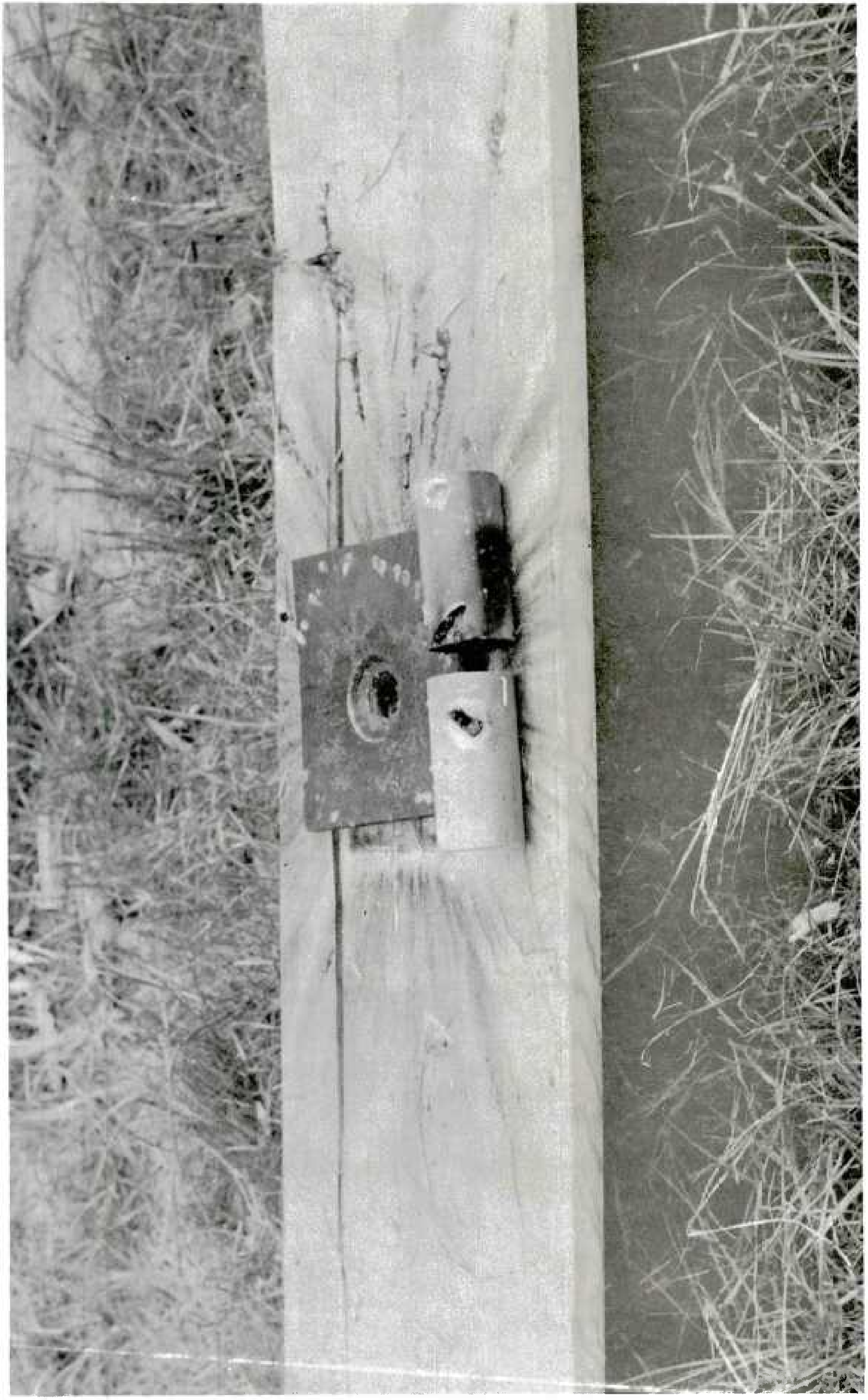


Figure 9. Posttest acceptor penetrations

Figure 10. Posttest low order detonation

Figure 11. Posttest confirmatory view

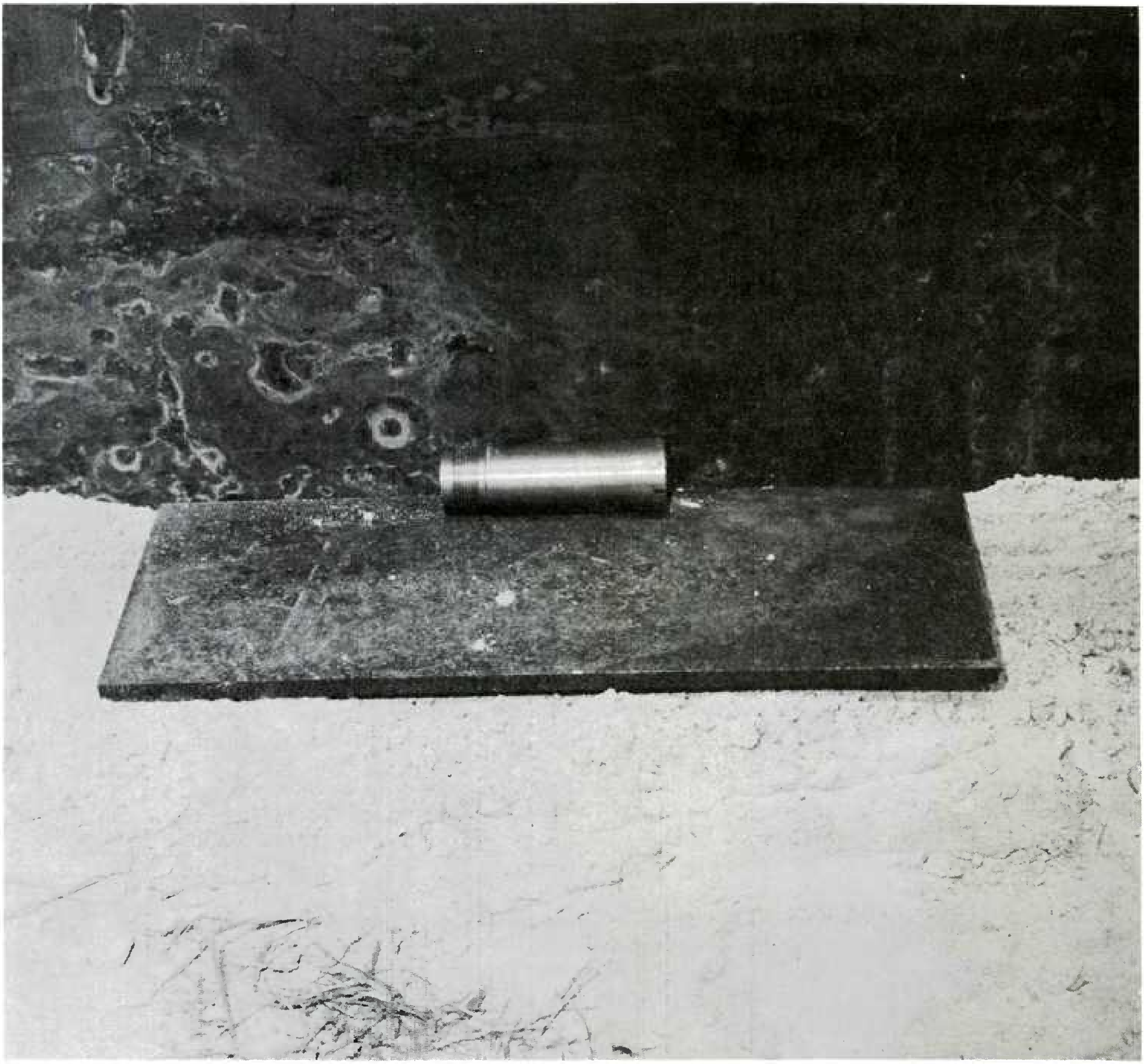


Figure 12. Wall pretest view of detonator (side-on)

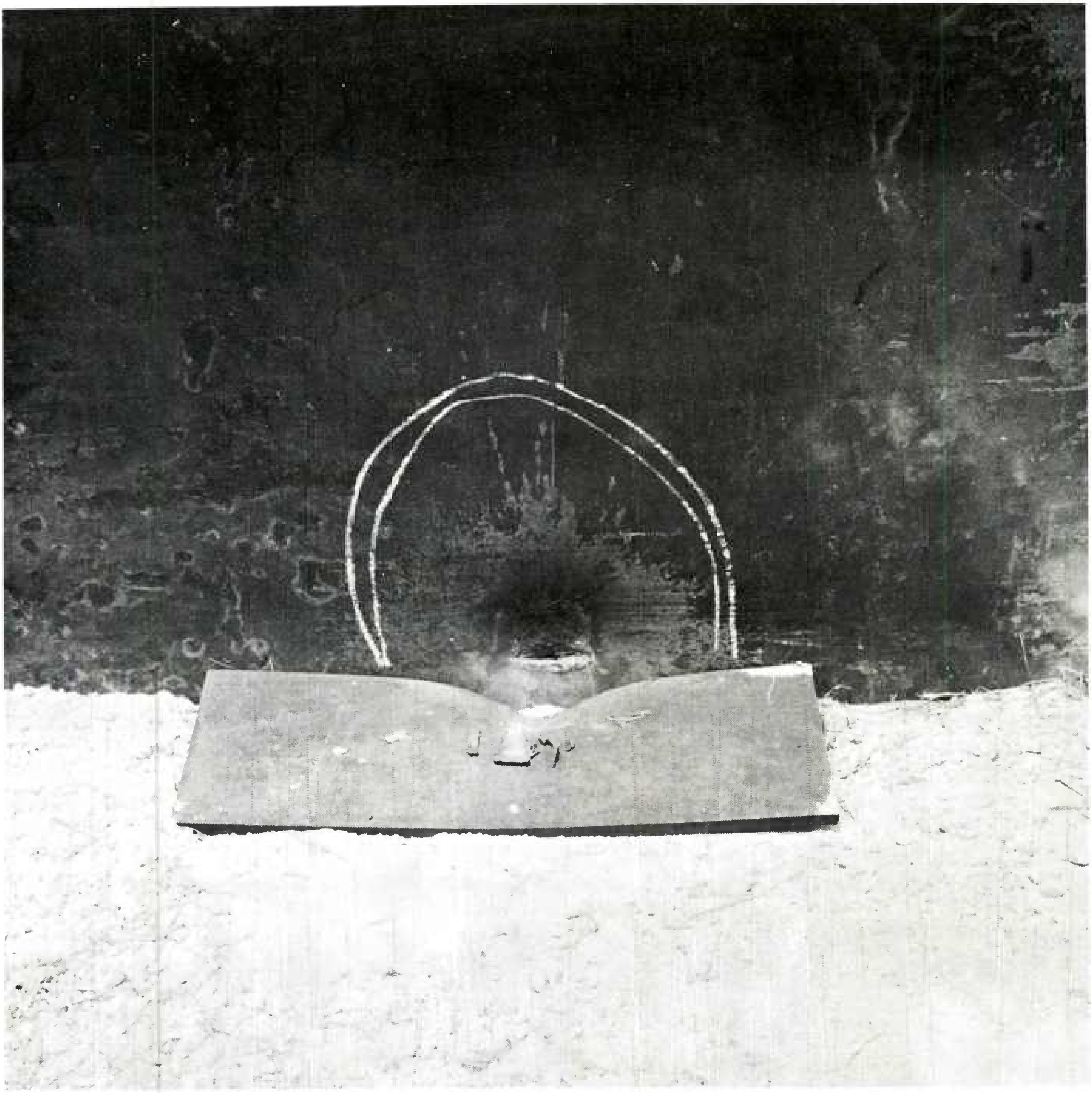


Figure 13. Front view of posttest

Figure 14. Back view of posttest

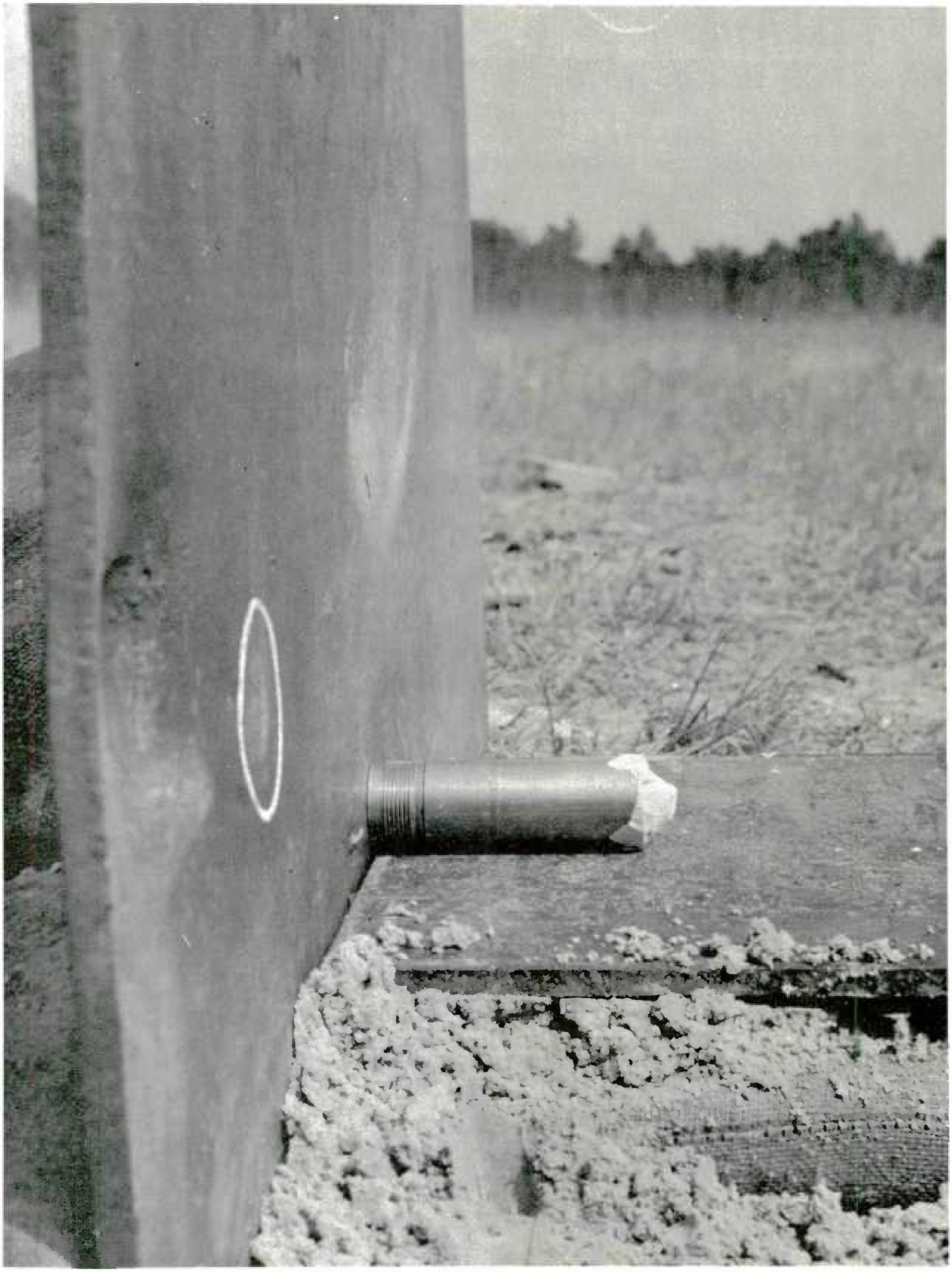


Figure 15. Wall pretest view of detonator (end-on)

Figure 16. Posttest view

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based on a statistical analysis of the test results has been evaluated in the text of this report. This appendix explains the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation depends on the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero, but the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \tag{1}$$

and, therefore, the expected value of (x) is given by

$$E(x) = np \tag{2}$$

Each confidence level will have a specific upper limit (p_2) depending on the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \tag{3}$$

where

$$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \tag{4}$$

Use of equation 3 is illustrated in the following example:

Example

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based on 30 observations without a reaction occurrence.

Given

Number of observations (n) = 30
Confidence level (α) = 95%

Solution

1. Substitute the given value of (α) into equation 4 and solve for ε:

$$\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$$

2. Substitute the given value of (n) and value of (ε) into equation 3 and solve for p_2:

$$\varepsilon = 0.025 = (1 - p_2)^{30}$$

or

$$p_2 = 0.116(11.6\%)$$

Conclusions

For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of (0.116 x 30) = 3.48 observations could result in a reaction for a 95% confidence level.

Probability Table

The probability limits and the range of the expected value E(x) for different numbers of observations are shown in table A-1. Three confidence limits, 90%, 95%, and 99%, are used to derive the probabilities. The same values are plotted in figure A-1.

Table A-1. Probabilities of propagation for various confidence levels

Number of observations	90% CL		95% CL		99% CL	
n	P_2	E(x)	P_2	E(x)	P_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

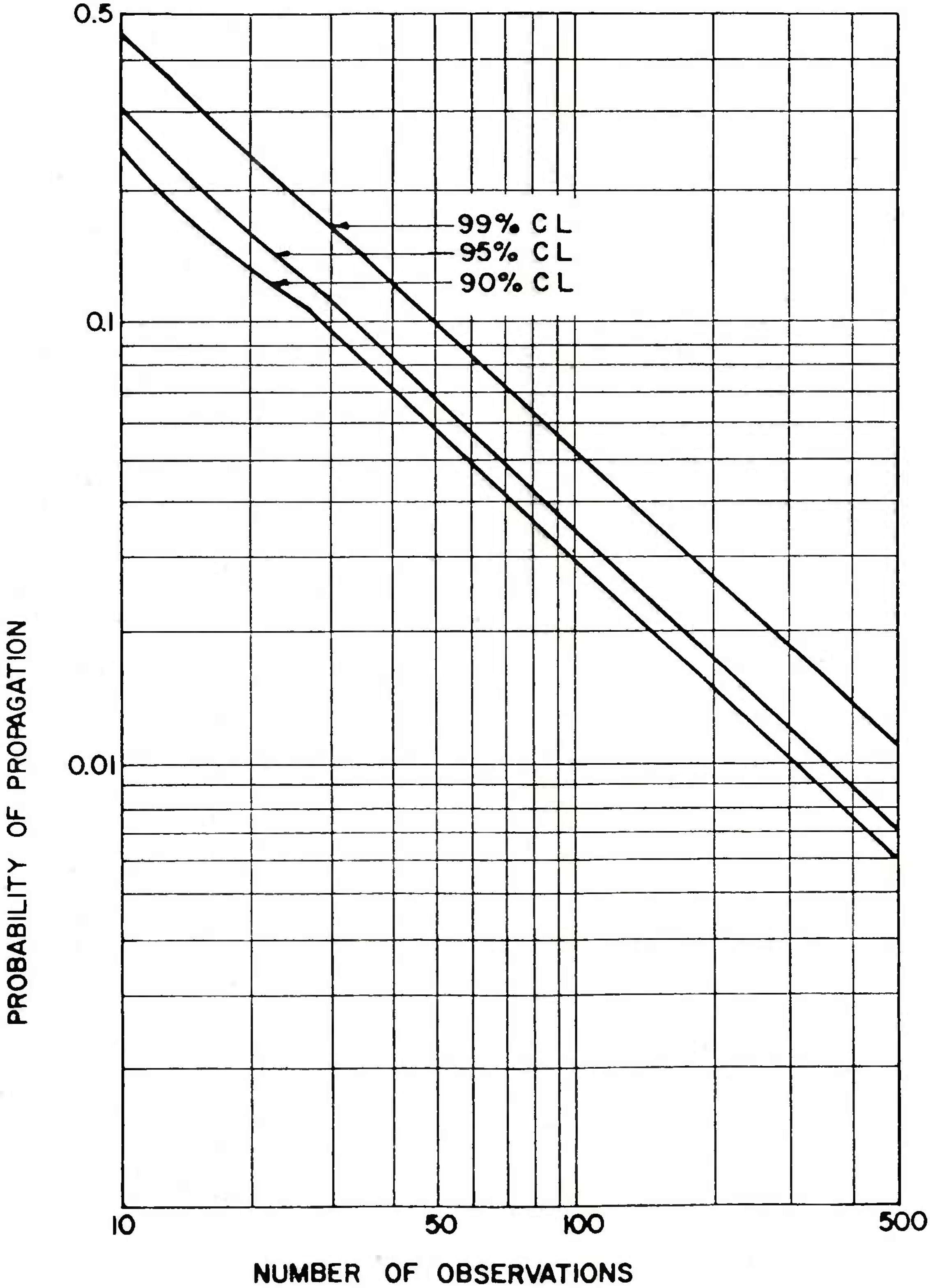


Figure A-1. Variations of propagation probability versus number of observations as a function of confidence level (CL)

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